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Strategies for the Prevention of a Successful Biological Warfare Aerosol Attack

COL Stanley L. Wiener, MC USAR

Biological warfare (BW) aerosol attacks are different from chemical attacks in that they may provide no warning/all clear signals that allow the soldier to put on or remove his M17/M40 protective mask. Methods are now being perfected to detect a BW aerosol cloud using an airborne (helicopter) pulsed laser system to scan the lower altitudes upwind from a troop concentration of corps size, and to sample and analyze the nature of the aerosol within a brief time interval. This system has certain limitations and vulnerabilities, since it is designed specifically to detect a line-type aerosol attack. Provision of, training with, and field use of a lightweight dust mist or HEPA filter respirator for each soldier is proposed for protection against undetected aerosol attacks. This particulate filter respirator would be issued in addition to the M17/M40 mask. Such a BW respirator will be able to purify the soldier's air by removing particles in the 0.3- to 15-μm-diameter range with an efficiency of 98 to 100%. Particle size of BW aerosols is in the same range, with an optimum size for high-efficiency casualty production of 1 to 5 μm mass median diameter. The proposed BW respirator will be lightweight; will require low inhalation pressures; will be comfortable to wear for prolonged periods; will not interfere with vision, hearing, and communication; and will not degrade overall effectiveness and performance to the degree observed with the M17/M40 masks. Such respirators would be worn as part of a contingency defense against an enemy likely to use BW agents. This respirator could be worn for prolonged periods when under threat of an undetectable BW attack during weather conditions favorable to the success of such an attack (i.e., low wind velocity and temperature inversion in the target area). In addition, tactically important assets such as command and control centers and missile batteries can also be protected continuously by air filtration systems powered by electricity (modular collective protection equipment). Vaccinations against anthrax, botulism, Q fever, plague, and tularemia are now available and immune protection against ricin and staphylococcal toxins appears feasible in the near future. Chemotherapy can also be provided for prophylaxis of infectious agents released on the battlefield. The vaccines and antibiotics can provide back-up protection against an unexpected BW attack during a period when the BW respirator is not in use or malfunctions due to a poor seal or filter leak. Enemy sites of biological weapon production, assembly, testing, and storage, and delivery vehicles can be targeted for destruction by bombs and/or missiles. An integrated, well-planned, BW defense with multiple components can decrease the likelihood of a successful enemy BW aerosol attack.

Introduction

Biological weapons pose a potential threat to military and civilian populations. The most likely mode of delivery of highly infectious or toxic agents is by aerosol. The aerosol particles produced by an attacker are expected to range in size from 0.3 to 15 μm diameter. These particles may be delivered by rockets, bomblets with aerosol nozzles, missiles, and aircraft equipped with tanks and spray nozzles; or by aerosol generators on small boats, trucks, or cars or operated from concealed positions on ground sites 1 to 50 km upwind from the target population.

If the aerosol agents enter the respiratory tract of the targeted individuals, there is a high probability that they will cause an unusually severe spectrum of disease and a high mortality rate. To prevent casualties from these weapons, it is essential to deny access of the aerosol particles to the airway and conjunctivae of the intended victims. If access to these sites is not blocked, then the existence of target host immunity to the biological warfare (BW) agent or the use of chemoprophylaxis for specific agents may prevent illness or reduce its severity.

Unique Features of BW Weapons

Biological warfare aerosols are usually invisible, odor- and taste-free, and not detectable by condensation of liquid droplets

Department of Medicine, University of Illinois College of Medicine at Chicago, Chicago, IL 60612.

Reprint requests: Stanley Wiener, M.D., MacNeal Hospital, 3249 South Oak Park Avenue, Berwyn, IL 60402.

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on the skin or uniform. Chemical agents may be detected by chemical alarms and tests, odor (phosgene, cyanide, mustards), or the rapid onset of symptoms (nerve agents causing headache, visual blurring, cholinergic and neurological symptoms; and mustards causing skin and eye discomfort). Chemical agents provide the victim with visual, olfactory, behavioral, and chemical test signals to put on the M17/M40A1 mask. There are rapid on-site, easy-to-perform chemical tests and detectors that monitor the surrounding air and provide the soldier with information that allows safe removal of the mask when the agent is no longer present.

The first evidence of a BW aerosol attack is expected to be a large number of casualties appearing within hours (toxins) or days (living organisms) after the infectious/toxic cloud has passed. The M17/M40 protective masks will deny aerosol particles access to the intended victims' airways and eyes if worn during the attack. Without the ability to detect a BW aerosol within a few seconds or minutes,, there is no signal provided for the soldier to put on his M17/M40 mask. Without a mask in place the infectious/toxic particles will enter the lungs and cause illness and death of a large percentage of the target population, unless that population has been immunized against the specific agent(s) used or effective post-exposure treatments are available. The success of the medical defense component depends on enemy use of vaccine-susceptible and antibiotic-sensitive agents, as well as effective, widely deployed, early-warning surveillance systems that can rapidly detect an attack and identify the agents used.

Current Attempts at Early Detection of a BW Attack

The LIDAR (light detection and ranging) system (Grotke M, Jecek B: personal communication) has been used experimentally to detect natural and artificially induced aerosol clouds; the components of the system include a pulsed laser mounted on a helicopter that flies perpendicular to the wind direction at altitudes up to 5,000 feet, and a reflecting telescope and photon detector that records scatter of photons when a cloud is encountered. The laser scans portions of the lower atmosphere vertically over an arc of 10 or more degrees and up to 100 km upwind. Once detected, specially equipped vehicles (Humm Vees) each with three air-sampling ports are positioned or moved to sample the cloud. These concentrated air samples are analyzed by BIDS (biointegrated detection system), which provides a plot of particle sizes (aerodynamic particle sizer); detects and classifies bacterial cells and measures DNA content (flow cytometer); measures ATP content using a bioluminometer; and identifies specific agents using immunoassays (*Bacillus anthracis*, *Staphylococcus* enterotoxin B, botulinum A toxin, and *Yersinia pestis*). Once the sample is received, the first three tests are completed in 4 minutes and the immunoassays are completed in 20 minutes. The laser image of the cloud may also be used to identify it as a BW aerosol (e.g., length, width, shape). In addition, information supplied by AWACS or J STAR systems may locate and identify the cloud-producing aircraft. Deployment of an adequate number of helicopters and vehicles (35 for a corps-size area) are required for this system to work effectively. At present only one or two aircraft and vehicles are being used to develop this system. Such an integrated detection scheme could provide the soldier with adequate warning time to put on his/her M17/M40A1 mask if the cloud is detected at least 4 km upwind.

The LIDAR/BIDS detection system is still under development. It is designed to protect corps-size troop deployments from a line BW aerosol attack. This system will probably not detect a close in attack mounted from concealed ground-level aerosol generators manned by Special Forces or terrorists; nor will it detect saturation of the area with bomblets capable of releasing aerosoled agents. The LIDAR/BIDS system is not designed to protect small targets such as airfields, moving armor units, and ships from tactical localized attacks. To increase the area coverage, reduce the time to cloud detection, and ensure almost constant surveillance of a large area (40,000 square miles), a squadron of unmanned aerial vehicles (8–12 UAVs) equipped with the LIDAR detection system could replace the helicopter-based system. Helicopters could be used instead of land vehicles to more rapidly reach and enter a detected cloud and sample it. Such a proposed system would provide the advantage of almost continuous surveillance of a target area and its perimeter and would not be directed only at a unidirectional line attack.

In addition, radar detection of attacking aircraft, missiles, and rockets will provide a signal to put on the M17/M40A1 mask in a combat zone where BW is a threat. The radar information identifies an attack but cannot predict whether the warhead or aircraft contains BW weapons. Our ability to rapidly evaluate the content of a suspicious missile warhead after impact requires further study and development.

The Concept of a Second Respirator for Individual BW Defense

Since there is no reliable signal for putting on or removing the M17/M40A1 mask, and because the LIDAR/BIDS system is only experimental and at best its use is currently limited to a line-type attack, there is a need for a lightweight personal particulate respirator that can be worn without discomfort for a prolonged period to protect troops vulnerable to an undetected BW aerosol attack.

The M17/M40A1 masks are relatively heavy (2.2 pounds); have increased inspiratory pressure gradients (50–60 mm of water), especially at high flow rates (100 l/minute); increase dead space by 300 ml, which can increase the $FiCO_2$ to 0.01 and decrease the FiO_2; cause facial sweating and thermal stress; produce a sense of confinement and a subjective feeling of breathing difficulty; cause decreased vision, impaired communication, and psychological problems (e.g., 10–20% rate of claustrophobia); cause facial skin irritation from pressure along the mask margin/seal; and leaks due to poor fit on an unusual facial configuration. These problems, plus an overall degradation in job performance of 26 to 51%, make it extremely difficult for soldiers to wear these masks for more than 3 or 4 hours at rest.[1,2] The ability of soldiers to perform continuous moderate to heavy work, as is required in combat, in full biological and chemical protective clothing and masks at 30° and 40°C with 50% relative humidity is limited to periods of 35 to 60 minutes. Attempting to work beyond these tolerance times is likely to result in heat illness.[3] Without masks guarding the airway, soldiers are vulnerable, for extended time periods related to meteorological conditions, to a BW aerosol attack. In the Gulf

War there were reports of soldiers attempting to sleep in their masks and protective clothing because of fear of a chemical or biological attack.[4]

A lightweight, easy to breath in BW respirator that can be worn continuously for up to 24 hours would be a useful additional piece of protective equipment to have in the field. Such a respirator worn to prevent airway access by a passing invisible BW aerosol could be removed briefly (e.g., 10 minutes) to allow eating/drinking without significantly increasing the probability of breathing in BW agents, since the exposure time would be so brief. A 10-minute unmasked period would only decrease protection against an attack launched at any time during a 1,440-minute (24-hour) period from 100 to 99.3%.

As long as there is no real-time warning signal of a BW attack, the only insurance against inhaling a fatal dose of a living pathogen or toxin is to wear a lightweight respirator during periods of possible/probable attack.

The degree of risk could be estimated from intelligence reports about the enemy's BW production facilities, storage inventory, numbers and types of delivery vehicles, a battle plan that includes BW use, a history of use, as well as careful meteorological monitoring for slow winds (3–7 mph) and temperature inversions. These respirators might only need to be worn when asleep in the early morning hours (i.e., the most frequent time for a temperature inversion that keeps the aerosol cloud close to the ground) or in high threat periods for intervals of over 24 hours.

BW respirators should be lightweight (e.g., less than 6 ounces); they should seal well about their contact with the face (half masks don't seal well over the bridge and sides of the nose, are uncomfortable and oppressive to wear for more than brief periods, and do not provide eye protection); be full face-pieces to provide eye protection with good preservation of the visual fields and visual acuity without water vapor condensation on the lenses; and they should have a small dead space; low inspiratory pressure (<25 mm of water) resulting in ease of breathing, and three to six layers of HEPA filters capable of excluding particles larger than 0.3 μm. Barring seal-related leaks, these simple masks should be capable of removing 99.9% of BW aerosol particles above 1 μm in size and 98 to 99% of particles below 1 μm in size.[5–7]

Effective BW aerosol attacks require particles of bacteria, viruses, or toxins in the 1- to 5-μm range. If BW respirators are worn during periods meteorologically favorable to an attack, they will prevent successful attacks and eventually discourage the enemy from the future use of these weapons against protected troops.

These individual particulate respirators could be developed to specifications similar to those described above or in a time of emergency could be obtained from commercial suppliers of full-face HEPA and/or dust mist respirators. The development of a lightweight protective mask has been planned for the first decade of the next century by the U.S. Army Chemical Research, Development, and Engineering Center, but this program could be accelerated. Each respirator and filters can be produced for less than $50, making the cost of protecting 500,000 men less than $25 million. Such masks may also protect the soldier's airway and eyes from irritating environmental dust and sand. These respirators could also be used by medical personnel caring for patients with contagious diseases such as pneumonic plague, hemorrhagic fevers, *Chlamydia psittaci* pneumonia, meningococcal disease, tuberculosis, and viral respiratory agents. The efficacy of lightweight respiratory protection has been demonstrated in the laboratory by Franz, who exposed mice to lethal aerosols of ricin (N = 6) and saxitoxin (N = 4); 100% of the animals in these experiments were dead in 72 hours and 10 minutes, respectively. When their mouth and nose was covered with two layers of military T-shirt material or cravat material, mortality in the ricin (N = 6) and saxitoxin (N = 8) groups was reduced to 0% (Franz DR, Commander, USAMRIID: personal communication, August 1995).

Use of BW Respirator Filters to Diagnose a BW Attack after Aerosol Inhalation but Prior to the Clinical Presentation of Casualties

Successful BW aerosol attacks are possible if a significant number of medically unprotected soldiers are noncompliant and do not use the BW respirators; or are not supplied with one; or their commanders decide not to order respirator use during meteorological threat periods; or an attack is launched despite adverse weather from the standpoint of BW and finds unprotected victims. If commanders do not want to use the masks during threat periods, they may choose to have 20 to 40 soldiers wear the masks in different parts of the corps area for 24 hours and then turn in their filters to an early detection/diagnosis laboratory that can test the filters for infectious agents/toxins each day. The next day, another group of soldiers can wear respirators and similarly turn in their filters, and so on. Such a surveillance system could warn of exposure to bacteria/toxins within 24 hours of an attack, providing time to start early treatment of exposed soldiers, assuming the agents used can be treated. Respirator filter data can be used to supplement other air samplers deployed in the field and LIDAR/BIDS data if available. The soldiers wearing the masks each day act like the miner's canary, but do not get ill or die. Their respirator filters can serve as detectors of a recent BW aerosol attack.

Training

It is essential that soldiers receive careful training with the M17/M40A1 mask and the proposed, but as yet undeveloped, lightweight BW respirator. This should include practice in use; changing filters according to a predetermined schedule; testing for filter and seal leaks and correcting leaks; cleaning, washing, and decontamination; and tactics for use during attacks (e.g., remaining quiet and breathing gently and quietly without moving the head rapidly, since the opposite actions increase the percentage of seal leakage; use of the M17/M40A1 mask during a chemical warfare (CW) or CW/BW combined attack instead of the BW respirator; switching back to the BW respirator after the chemical all clear is announced.) Seal leaks are the most important mechanism by which mask wearers can become BW or CW casualties. Multilayered HEPA filters are unlikely to leak and should filter more than 99.9% of 1- to 5-μm particles. Face-seal leaks may reduce mask efficiency by as much as 10 to 20% and could result in casualties.[7] Individual facial-fit testing is required to correct seal leak problems. The M40A1 mask can be checked for leaks by use of the M41 protective mask-fit valida-

tion system. This portable device provides particle counts inside and outside of the mask. The ratio of these counts is a measure of the leak rate. Filtering full face-piece respirator leakage can be measured by monitoring the pressure of air injected into the respirator cavity and withdrawn.[8] This method is not suitable for mass testing in the field.

Collective Protection[9] (Gulian W, Thompson J, Chemical Biological Defense Command, Aberdeen Proving Ground, MD: personal communication, 1994)

Modular Collective Protection Equipment (MCPE) has been developed and distributed to active U.S. Army units. Such equipment requires extensive training for proficiency, and this aspect of deployment has not always been complied with. The equipment consists of a filter unit for gases (metal ion-impregnated carbon) and HEPA filters for the removal of aerosol particles. Individual filter units can filter 100 or 200 cubic feet of air/minute at the expense of 500 W/100 cubic feet of air filtered. The air pressure in the space receiving filtered air is kept positive so that leakage is inside to outside and pathogens and toxins are excluded. Within the shelter, room, or vehicle, the soldier can remove his mask and protective clothing and work in a shirt-sleeve environment. MCPE may be fitted at the factory or retrofitted to trucks, the M1A1 tank, armored personnel carriers, hospital modules, anti-missile batteries, and command, control, and communication centers. The filtered air may be electively cooled or heated. Air-flow requirements per individual are 20 cubic feet/minute, so that a 600 cubic foot/minute filter unit would provide air for 30 soldiers. Other air flowing through the filters replaces leaking air and provides air flow to wash out the protective entrance to the shelter. Such shelters are vulnerable to loss of power and fragment penetration or filter system damage. Collective protection for shelters and vehicles may be operated continuously to ensure protection against undetected BW or CW attacks. Collective protection will be limited in availability near the battlefield and will be prioritized to protect essential combat and combat support elements. Individual protective equipment should be closely available in case the MCPE fails to function.

Tightly constructed buildings without sealed and/or positive-pressure rooms do not provide protection against outside aerosols and may trap agent within the building, delaying its inactivation and clearance.[10–11] Similarly, dense forests also provide no defense against BW aerosols (Patrick W, BW consultant, USAMRIID: personal communication, August 1995). Sealed rooms and chemical protective masks were used by Israel to protect its civilian population during the Gulf War. Problems encountered included increased carbon monoxide levels in the rooms, respiratory distress in the elderly and some patients with cardiopulmonary disorders, difficulty in wearing masks for a sustained period, and inability of some to use the mask unless it was blower-actuated. As reported by others, claustrophobia and anxiety were prevalent.[12]

Vaccines

In addition to the use of respirators and collective protection to protect the soldier's airway from penetration by BW agents, immunization against specific living agents can provide a second line of defense if physical measures are defective or inadequate or are overwhelmed. Vaccines and prophylactic antibiotics provide insurance against respirator failure (e.g., filter or seal leak) or an undetected BW aerosol exposure of troops not using respirators.

The following vaccines are available or can be made available to deployed U.S. Army personnel:

Anthrax vaccine. This is a formalin-inactivated vaccine made with protective antigen (PA). Primary immunization requires six 1-ml doses given at 0, 2, and 4 weeks and at 6, 12, and 18 months, followed by annual booster injections. This vaccine (MDPH-PA) did not fully protect guinea pigs against an intramuscular challenge with the Ames (42–58% survival) or New Hampshire strains of *B. anthracis*.[13] However, two doses of the same vaccine were highly effective in completely protecting Rhesus monkeys against 500 aerosol lethal doses of Ames strain spores 8 weeks and 2 years after their first dose of vaccine (Ivins BE: personal communication, 1994). MDPH-PA vaccine was given to soldiers during the Gulf War. Antibody developed in 85 to 95% after the first three doses.[14] A live anthrax vaccine is used in the former U.S.S.R. to immunize livestock and human beings. It is a spore vaccine (STI-1 and strain 3 mixture) and has reduced human cutaneous anthrax 75 to 84% in field trials in Middle Asia. It was 60% effective against the subcutaneous challenge of guinea pigs with virulent strains of anthrax within 3 weeks of administration.[15] Resistance to anthrax is partly related to cell-mediated immunity and does not correlate with serum antibody level, although humoral response plays an important role. A live spore vaccine is claimed by the Russians to be superior in stimulating cell-mediated immunity than the MDPH-PA vaccine. Preliminary use of the chemical PA vaccine followed by use of the live vaccine has been proposed by Russian investigators.[15]

Botulinum toxoid vaccine.[14,16,17] This pentavalent vaccine protects against toxin types A, B, C, D, and E, but provides no protection against the F- and G-type toxins. Strains of *C. botulinum* producing toxins F and G are difficult to grow in large quantities and those toxins are unlikely to be weaponized. The vaccine is given in a 0.5-ml dose subcutaneously at 0, 2, and 12 weeks. These doses produce antibody in 83% of subjects after three doses and in 100% after four doses. Protection against toxin is often present after one or two doses, and before the appearance of antibody by enzyme-linked immunosorbent assay or a mouse neutralization assay. In studies utilizing nonhuman primates, protection against an aerosol challenge may appear after only two doses of vaccine in some recipients. Annual booster doses are recommended. Very low concentrations (<0.02 IU/ml) of specific serum antibody are effective against aerosol challenge with specific toxin. Enemy use of difficult-to-produce type-F and/or type-G toxins could render the protection provided by this vaccine useless until it can be made heptavalent, but such use is unlikely. A heptavalent antitoxin against types A–G is available in limited supply at USAMRIID (Fort Detrick, Frederick, MD).

Tularemia vaccine.[14] Live vaccine strain is administered as a single dose intradermally by a multiple-pressure technique. Protection to aerosol challenge occurs at 3 weeks post-vaccination and immunity to 1 to 10 ID_{50} is present in 80% of subjects.

Inhalation of 100 ID_{50} reduces protection to 52%, and inhalation of 1,000 ID_{50} reduces protection to 24%. Other studies have demonstrated complete protection of human volunteers to aerosol exposure to 500 to 1,000 ID_{50} of virulent *Francisella tularensis* 2 months after intradermal immunization. This protection fell to 53% protection of volunteers at 14 months, suggesting a need for a booster dose or varying immunogenicity of various vaccine lots.[18,19]

Plague vaccine.[14] This is a whole cell formalin-killed product. Doses of 0.5 ml i.m. can be given at 0, 1, and 2 weeks. It is effective against intradermal exposure (i.e., flea bites) but not against natural aerosol exposure and probably does not prevent plague pneumonia. Plague vaccines under development may protect against aerosol exposure.

Q fever vaccine.[14] A formalin-inactivated whole cell vaccine is available as an investigational vaccine in the United States. Pre-vaccination skin testing for existing immunity is required to prevent potential severe local reactions to the vaccine in immune individuals. One dose provides relative immunity to aerosol challenge within 3 weeks. Booster injections are not required. Medical defense interventions against the most likely threat agents are summarized in Table I.

Experimental vaccines have been effective in preventing death and alveolar damage in mice exposed to aerosoled ricin;[20] and death in mice exposed to aerosoled staphylococcal enterotoxin B. Similar vaccines will soon be tested in humans. Monoclonal antibodies to ricin have been produced in a hybridoma system, and these antibodies may have potential use for toxin neutralization in vivo.[21]

Prophylactic Chemotherapy

During the Gulf War, ciprofloxacin was available for pre-attack prophylaxis. This drug has antibacterial activity against some strains of *B. anthracis*, *Y. pestis*, and *F. tularensis*. Resistant strains exist. If the identity of the prophylactic antibiotic is revealed during a conflict, a dedicated offensive BW strategist is likely to use an organism(s) resistant to the available prophylactic antibiotic and other stockpiled antibiotics available in the region. Similarly, the types of vaccines and antitoxins administered and stockpiled should remain classified throughout the conflict.

Role of Intelligence and Military Intervention in BW Defense

Identification of threat agents prior to the onset of a conflict allows medical planners and research scientists to develop vaccines and stockpile antibiotics. Unfortunately, intelligence information is seldom complete and some agents may be weaponized, for which there is no available medical defense (e.g., a new agent or an antibiotic- and/or vaccine-resistant strain of a known agent).

Intelligence methods can also locate sites of BW weapon research, production, weaponization, and storage; routes and means of transport; and vehicles of dissemination. Such sites can be targeted for destruction by aerial bombs or missiles, as was done in Baghdad and Salman Pak in the Gulf War. Some potential adversaries of the United States are now protecting military activities by tunneling into mountains. These sites pose

TABLE I

CURRENT MEDICAL DEFENSE AGAINST MAJOR BW THREAT AGENTS

Agent (Disease)	Vaccine/Schedule[a]	Protection by Week	Post- or Pre-Exposure Antibiotic (AB) or Antiviral (AV) or Antitoxin (AT)	Effective Antibiotic or Antitoxin Must Be Given Within *N* Days of Exposure
Bacillus anthracis (inhalation anthrax)	1 ml i.m. at 0, 2, 4 weeks, then at 6, 12, 18 months; booster 1 ml each year (L)	4[b]	+AB; availability will depend on the agent sensitivity profile and stockpiled supplies	1–2
Yersinia pestis (bubonic plague)	1 ml i.m. 0 time, 0.2 ml at 1 month and 3 months or 0.5 ml at 0, 1, 2 weeks; booster 0.2 ml each year (L)	3[c]	+AB; availability will depend on the agent sensitivity profile and stockpiled supplies	1–2
Francisella tularensis (tularemia)	Live virus 1 dose i.d. by multiple-pressure technique (I)	3	+AB; availability will depend on the agent sensitivity profile and stockpiled supplies	1–2
Clostridium botulinum (botulism)	Toxoid (types A, B, C, D, E) 0.5 ml s.c. at 0, 2, 12 weeks; booster 1-year intervals (I)	3–14	+AT; Heptavalent antitoxin types A–G (USAMRIID); trivalent antitoxin to types A, B, E (Centers for Disease Control)	1
Variola virus (smallpox)	Vaccination by scarification; booster every 5 years (L)	2	+AV; methisazone; vaccinia immune globulin	3
Coxiella burnetii (Q fever)	One dose s.c.; skin test required to exclude prior infection (I)	3	+AB; availability will depend on the agent sensitivity profile and stockpiled supplies	2

[a] L = licensed; I = investigative.

[b] Only partial protection of guinea pigs from Ames and New Hampshire strains of *B. anthracis*.

[c] No protection against pneumonic plague.

difficulties in determining the nature of the concealed/protected activity. Such hardening may limit our ability to destroy previously vulnerable military targets such as BW production facilities by conventional weapons during a future war.

The Integrated Multifaceted BW Defense in the Gulf War

BW defense for the Gulf War was organized and deployed during the early months of Desert Shield. Vaccine supplies were initially in short supply in some areas, but 150,000 soldiers were immunized against anthrax and botulinum toxins in a brief period of time. Surveillance upwind of troop units for BW agents with air samplers was performed, but the wide area of troop deployment made 24-hour a day, daily surveillance extremely difficult. Prewarning or realization of an attack prior to the appearance of casualties was possible if detected by air sampling/agent identification methods. The only physical protection for the soldier against inhalation of pathogens or toxins was the chemical mask, and this was only usable for brief periods. Ciprofloxacin was stockpiled and widely distributed (30 million doses) for prophylactic/therapeutic use. Unmasked, our personnel were essentially vulnerable to BW aerosol attacks with agents resistant to vaccines and antimicrobials, or for which vaccines and antimicrobials did not exist or were unavailable. Some of these problems were anticipated in prior reviews.[22,23] Coalition Forces control of the air and adjacent bodies of water reduced the probability of delivery of BW agents upwind from our forces. Sites of possible BW production and storage and possible delivery vehicles were targeted and attacked. Direct and veiled threats of possible retaliation against Iraq with thermonuclear weapons is also believed to have been an important deterrent against BW use. These military and diplomatic measures were important components of the integrated, multifaceted BW defense utilized by Coalition Forces in the Gulf War.

References

1. Shemer J, Nehama H: Medical limitations of gas masks for civilian populations: the 1991 experience. Milit Med 1992; 152: 444–6.
2. Johnson AT, Weiss RA, Grove C: Respirator performance rating table for mask design. Am Ind Hyg Assoc J 1992; 53: 193–202.
3. McLellan TM: Work performance at 40°C with Canadian Forces Biological and Chemical Protective Clothing. Aviat Space Environ Med 1993; 64: 1094–100.
4. Fullerton CS, Ursano RJ: Health care delivery in the high-stress environment of chemical and biological warfare. Milit Med 1994; 159: 524–8.
5. Chen CC, Lehtimaki M, Willeke K: Aerosol penetration through filtering facepieces and respirator cartridges. Am Ind Hyg Assoc J 1992; 53: 566–74.
6. Yamada Y, Katsuhiro M, Mori T, et al: Penetration of submicron aerosols through high-efficiency air filters. Health Physics 1984; 46: 543–7.
7. Chen S-K, Vesley D, Brosseau LM, et al: Evaluation of single-use masks and respirators for protection of health care workers against mycobacterial aerosols. Am J Infect Control 1994; 22: 65–74.
8. Brown RC, Vaughan NP: Measurement of the leakage and fit factor of a filtering facepiece by continuous monitoring of pressure pulsations. Am Ind Hyg Assoc J 1993; 54: 409–16.
9. Benton DR, Jones MR: Modular Collective Protection Equipment. Department of the Army Publication. Aberdeen Proving Ground, MD, Chemical Research, Development and Engineering Center, Physical Protection Directorate, 1990.
10. Meselson M, Guillemin J, Hugh-Jones M, et al: The Sverdlovsk anthrax outbreak of 1979. Science 1994; 266: 1202–7.
11. Cristy GA, Chester CV: Emergency Protection against Aerosols (report No. ORNL-5519). Oak Ridge, TN, Oak Ridge National Laboratory, July 1981.
12. Goldsmith JR: Prevention, gas masks, and sealed rooms: a public health perspective. Public Health Rev 1992/93; 20: 342–6.
13. Ivins BE, Fellows PF, Nelson GO: Efficacy of a standard human anthrax vaccine against *Bacillus anthracis* spore challenge in guinea-pigs. Vaccine 1994; 12: 872–4.
14. Biological Defense: Vaccine Information Summaries. Publication of USAMRIID. Frederick, MD, Fort Detrick, 1994.
15. Shlyakhov EN, Rubinstein E: Human live anthrax vaccine in the former USSR. Vaccine 1994; 12: 727–30.
16. Franz DR, Pitt LM, Clayton MA, et al: Efficacy of prophylactic and therapeutic administration of antitoxin for inhalation botulism. In Botulinum and Tetanus Neurotoxins, pp 473–6. Edited by Dasgupta BR. New York, Plenum Press, 1993.
17. Middlebrook JL: Contributions of US Army to botulinum toxin research. In Botulinum and Tetanus Neurotoxins, pp 515–9. Edited by Dasgupta BR. New York, Plenum Press, 1993.
18. Waag DM, Galloway A, Sandstrom G, et al: Cell-mediated and humoral immune responses induced by scarification vaccination of human volunteers with a new lot of the live vaccine strain of *Francisella tularensis*. J Clin Microbiol 1992; 30: 2256–64.
19. Hornick RB, Eigelsbach HT: Aerogenic immunization of man with live tularemia vaccine. Bacteriol Rev 1966; 30: 532–8.
20. Hewetson JF, Rivera VR, Creasia DA, et al: Protection of mice from inhaled ricin by vaccination with ricin or by passive treatment with heterologous antibody. Vaccine 1993; 11: 743–6.
21. Lemley PV, Amanatides P, Wright DC: Identification and characterization of a monoclonal antibody that neutralizes ricin toxicity in vitro and in vivo. Hybridoma 1994; 13: 417–21.
22. Hayes DP, Marrese M: Chemical-biological warfare: medical logistics and defense. Milit Med 1991; 156: 321–7.
23. Wiener SL: Strategies of biowarfare defense. Milit Med 1987; 152: 25–8.